Development of a Multi-Sensor Navigation Filter for High Accuracy Positioning in all Environments

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SPACE Partners

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- Civil Aviation Authority
- EADS Astrium
- Leica Geosystems
- Ordnance Survey
- Nottingham Scientific Ltd
- QinetiQ
- Thales

SPACE Aim and Objectives

Robust, Accurate Positioning in Difficult Environments

'Centimetres Everywhere'

- Higher sensitivity algorithms for signal acquisition and tracking in harsh environments
- Exploitation of new signals
- Improved sensor error modelling
- Robust integrity and quality monitoring algorithms
- Integration of different sensors and data sources

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SPACE Priority Environment
Transition Zone

- Indoor and Urban are key areas
- We define scenarios around *transitions*
- A transition is where the quality of the GNSS signal changes significantly

Good environment

Good environment with local masking and some multipath

Indoors: Significant masking and multipath

Very little signal penetration

Plug and Play Sensor Integration

- Positioning sensors
  - GNSS (GPS/Glonass/Galileo)
    - *SBAS*
    - *High sensitivity GPS*
    - *A-GPS*
  - Pseudolites / Locatalites
  - Dead reckoning
    - *INS*
    - *compass/gyro/odometer combinations*
  - UWB
  - Bluetooth
  - Imaging sensors
- Velocity sensors
- Attitude sensors
- Others…

Plug and Play Filter Design

- Needs to be
  - flexible
  - easy-to-use
  - extendable
- No single navigation algorithm is suitable
  - want to try different linear combinations of measurements
  - want to model different states e.g. gyro bias, scale factors, misalignments
  - want cascading filters, single filter, feedback
- Integrate at a minimum
  - GPS / Galileo
  - Pseudolites / Locatalites
  - UWB / Bluetooth
  - INS / Dead Reckoning Sensors
  - Imaging sensors

Plug and Play Filter Design

- Identified three levels of user with different requirements:
  - Level 1: Default functionality that will reconfigure when different sensors are used
  - Level 2: User decides which states and modelled, and how the measurements are used
  - Level 3: Extendable functionality where user can add different states and measurement types

Filter States

- States are what the filter estimates
  - User definition of which states to model
- Defined procedure for adding states in future
- Current states implemented:

Position (Lat, long, height)	INS Position
Velocity (Nav frame)	INS Velocity
Acceleration (Nav frame)	INS Attitude
Jerk (Nav frame)	Gyro bias
Δ∇Ambiguities (1 per ΔΔ∇ range, multiple frequencies) *	Gyro scale factor
ΔΔ∇L1 Ionosphere (1 per ΔΔ∇ range) *	Accelerometer bias
Receiver clock (1 per receiver) *	Accelerometer scale factor

Process Noise

- User definitions of where the noise enters the system
- Defined procedure for further spectral densities in future
- Currently implemented:

Position (Nav frame)	Gyro noise
Velocity (Nav frame)	Gyro bias
Acceleration (Nav frame)	Gyro scale factor
Jerk (Nav frame)	Accelerometer noise
$\Delta\nabla$Ambiguities (1 per $\Delta\nabla$ range, multiple frequencies) *	Accelerometer bias
$\Delta\nabla$L1 Ionosphere (1 per $\Delta\nabla$ range) *	Accelerometer scale factor
Receiver clock (1 per receiver) *	

Measurements

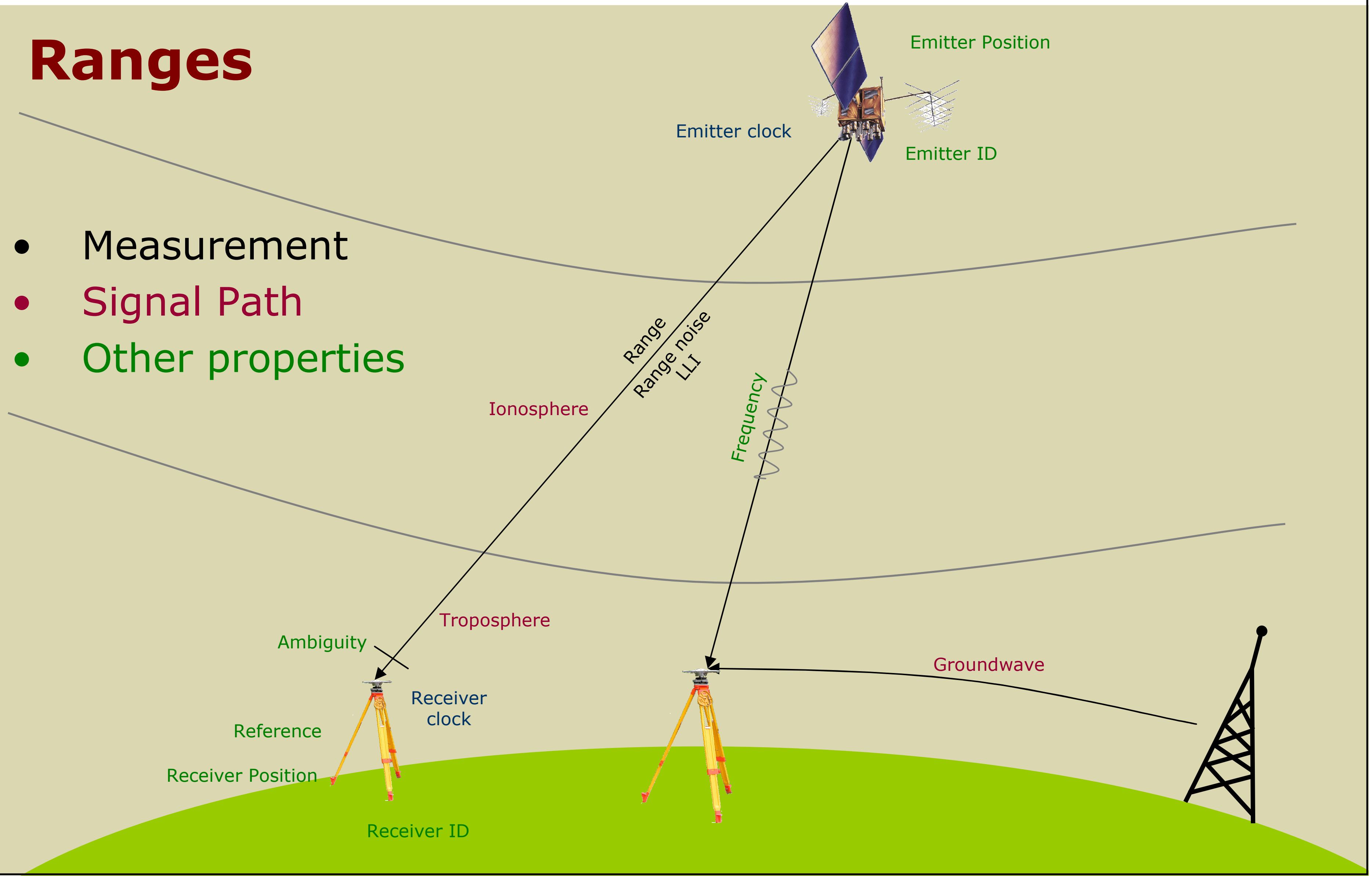
- 5 generic types of measurement input:

Range
Range rate
Position
Velocity
Attitude

- Measurements not defined by system (e.g. GPS, Bluetooth), they are defined by their properties
- Reformats measurements to form linear combinations and performs single, double differencing
- Defined procedure for adding measurements in the future

Ranges

- Measurement
- Signal Path
- Other properties



Filter Functionality

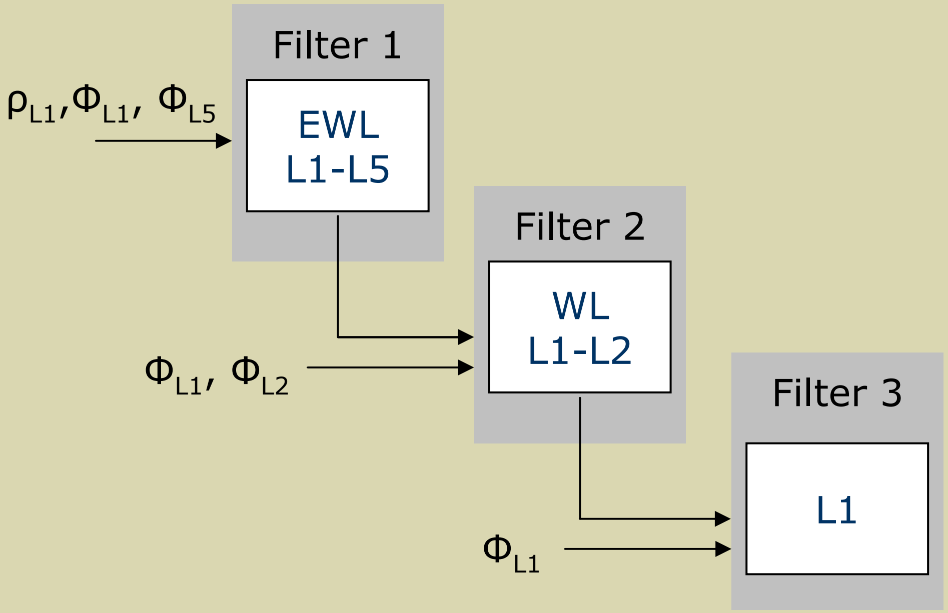
- Prediction models
  - INS
  - Dead reckoning
  - Unknown dynamics
- Integration of any position, velocity, attitude, range or range rate sensor e.g.
  - GPS
  - GPS+Galileo
  - GPS+Galileo+INS+Bluetooth
  - GPS+UWB+DR+…
- Easily configurable for single or multiple/ cascading/ decentralised/ centralised filtering approaches
- Extendable

Example of Use

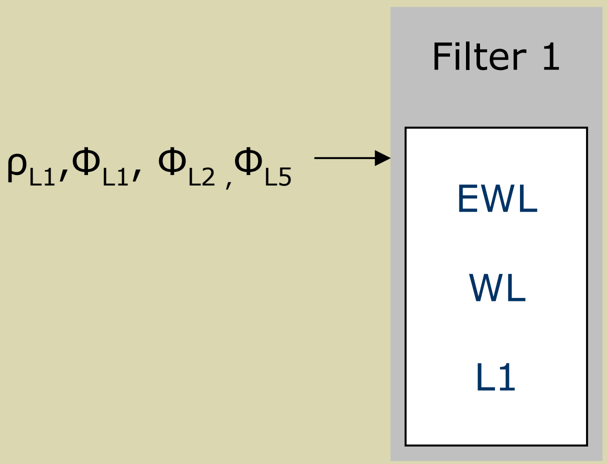
- GPS and INS integration
  - Any number of IMU states e.g. gyro and/or accelerometer biases, scale factors etc
  - Subset of navigation states e.g. don't model height
  - Measurement updates from any system e.g GPS, Bluetooth, UWB, zero velocity, attitude updates
  - Feedback possible
  - Tight or loose integration algorithms (+ deep when fully integrated with software GPS receiver)
  - Forward, backward or smoothed
  - Extendable, e.g. for lever arm estimation

Examples of Use (2)

- TCAR for GPS+Galileo ambiguity resolution
  - Linear combinations of observations (wavelength vs ionospheric effect vs noise)



3 filter cascaded



Single filter cascaded

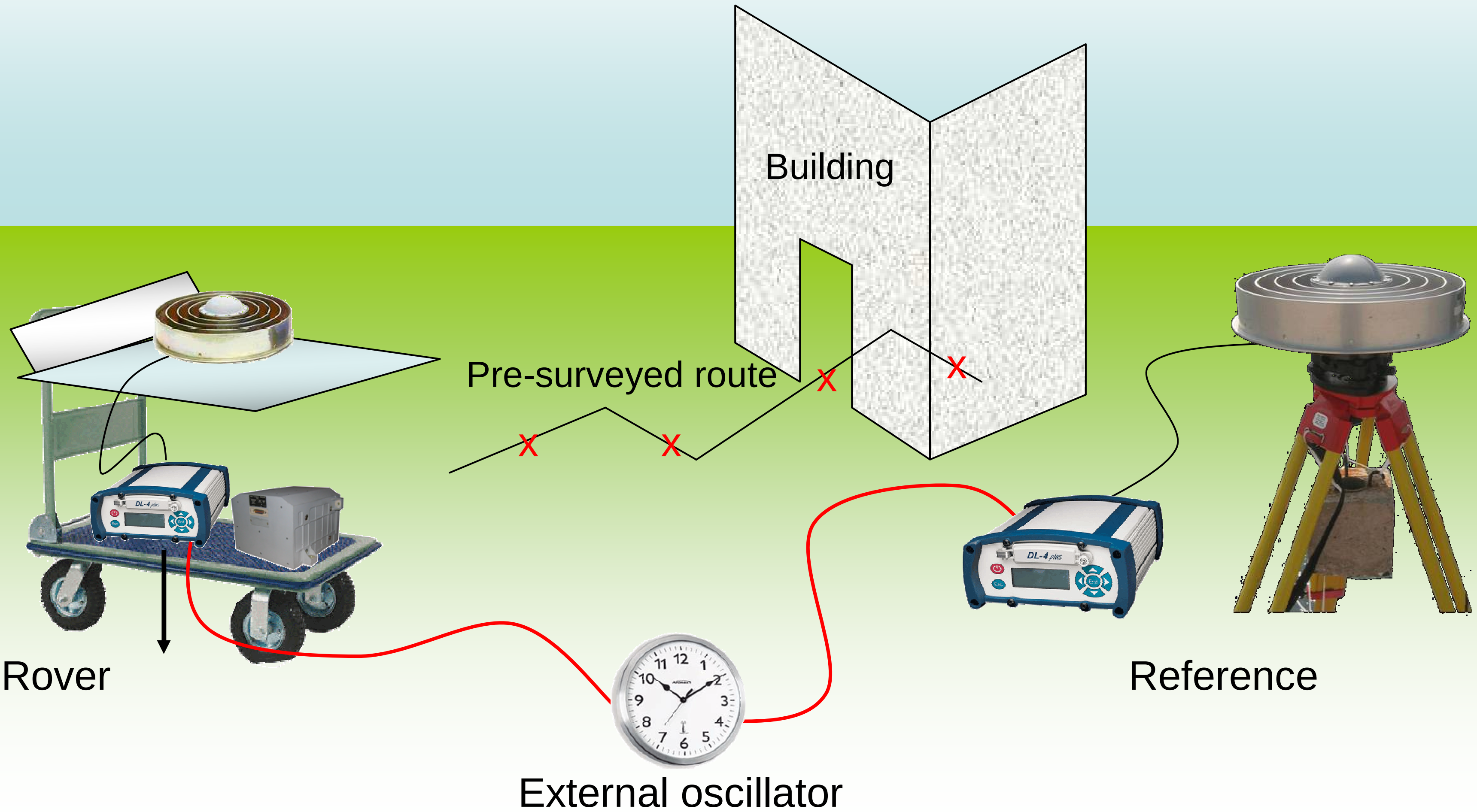
Examples of Use (3)

- Non-integer ionosphere free combinations can be configured easily
  - Dual or even triple frequency combinations
  - e.g. for modernised GPS

System	LC	Coefficients			λ_{LC}	$\nabla\Delta\sigma_i$ (m)	α_I & β_I
		k_1	k_2	k_3			
GPS	IF_{12}	1	$-\frac{\lambda_1}{\lambda_2}$	0	$\frac{\lambda_1\lambda_2^2}{\lambda_2^2-\lambda_1^2}=0.4844$	0.0246	0
	IF_{13}	1	0	$-\frac{\lambda_1}{\lambda_3}$	$\frac{\lambda_1\lambda_3^2}{\lambda_3^2-\lambda_1^2}=0.4302$	0.0215	0
	IF_{23}	0	1	$-\frac{\lambda_2}{\lambda_3}$	$\frac{\lambda_2\lambda_3^2}{\lambda_3^2-\lambda_2^2}=2.9929$	0.1658	0

Source: Zhang, W., 2005, Triple frequency cascading ambiguity resolution for modernized GPS and Galileo, MSc Thesis

SPACE Reference Environment



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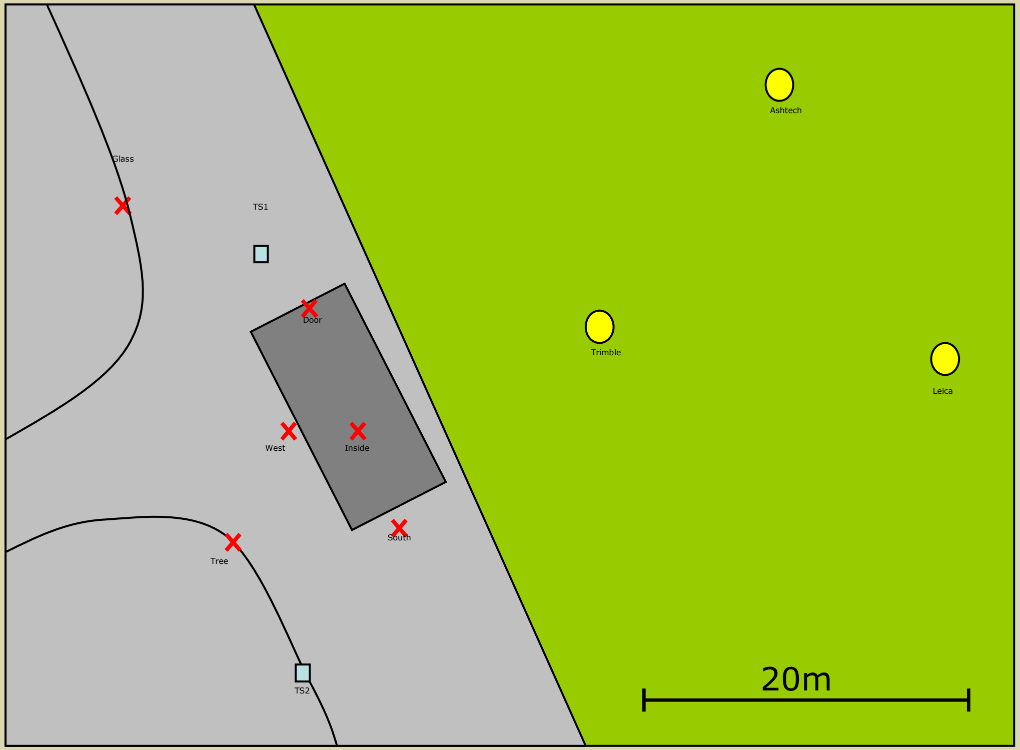
SPACE Reference Environment Location

- University of Nottingham Sutton Bonnington Campus
- Brick storage barn next to field



SPACE Reference Environment
Initial Survey

Total station survey

Laser Scanner

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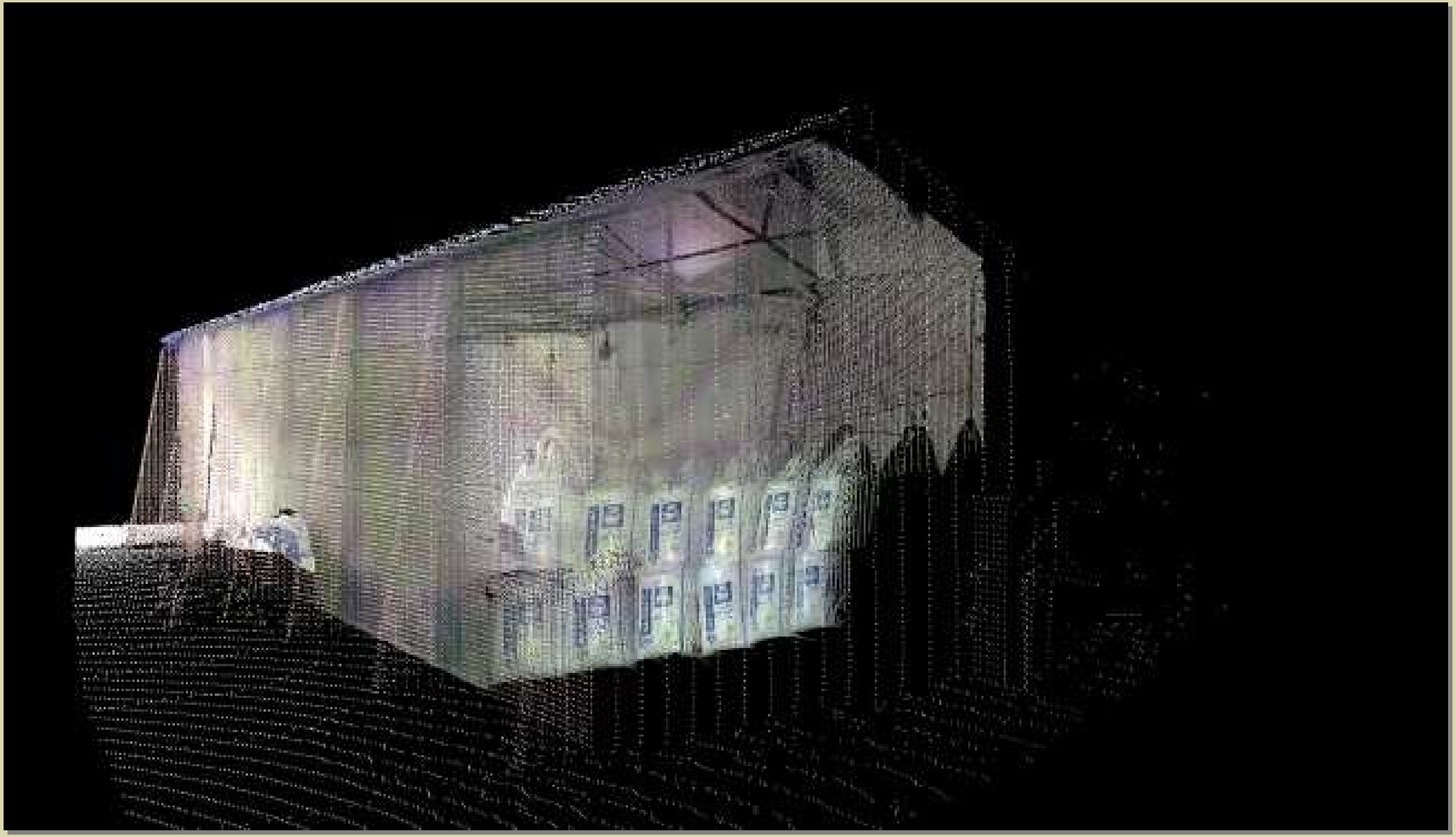

SPACE Kinematic Field Trial

- Navigation Grade INS
- Fixed reference points (5)
- Miniature rail track
  - Repeatable trajectory
- GPS, INS on riding car
- Large aluminium reflector
- Update points between fixed reference points

Aberporth trials

- ‘Ideal’ test data set
- Aberporth airport, Wales
  - Clear GPS environment
  - Runway
- Applanix POS-RS
  - Honeywell CIMU
- Different speeds between 20 and 70mph
- Different Dynamics
- 20 minute static at each end of trajectory
- POSPac software solution used as reference

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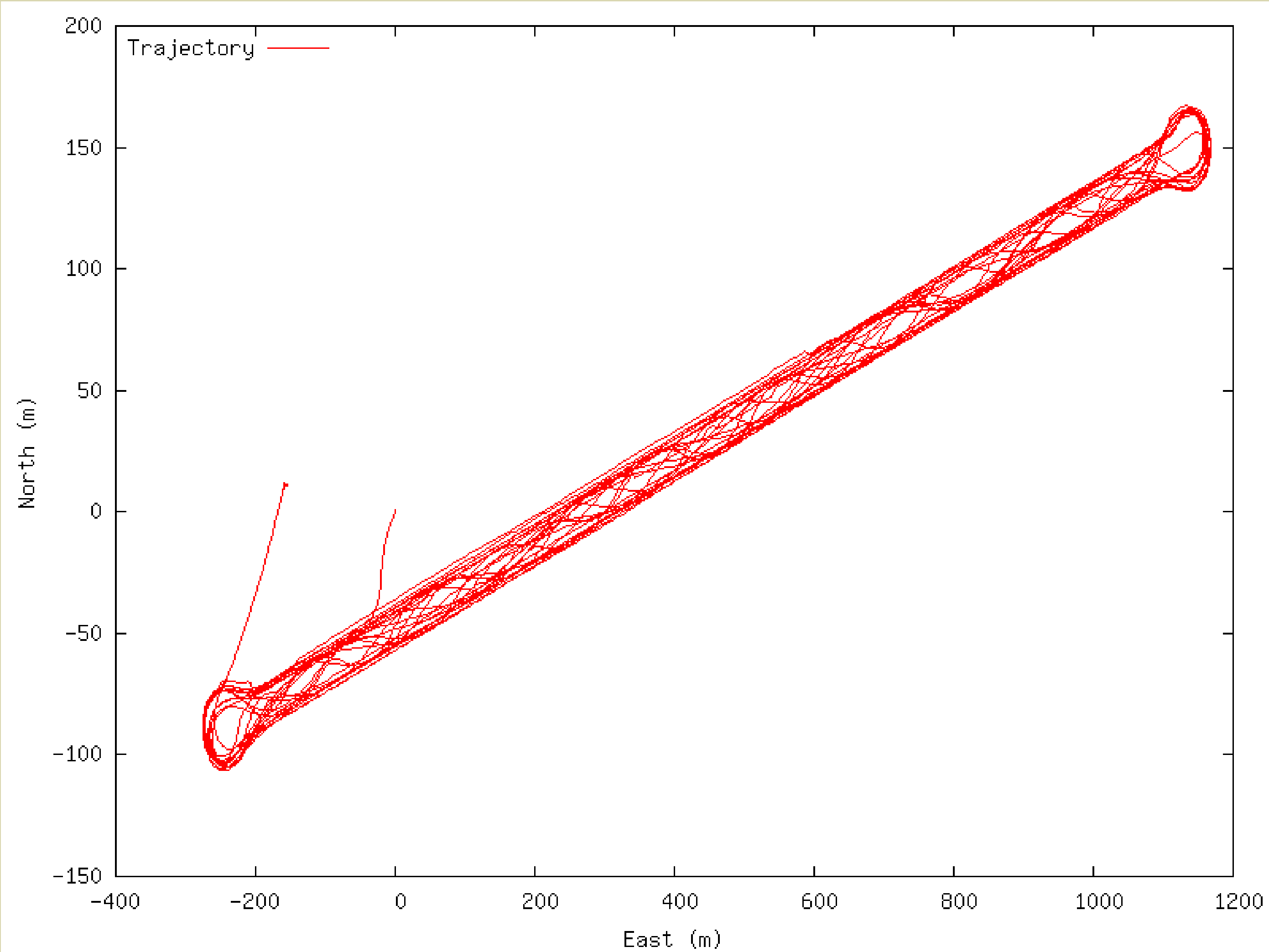
Aberporth Trajectory

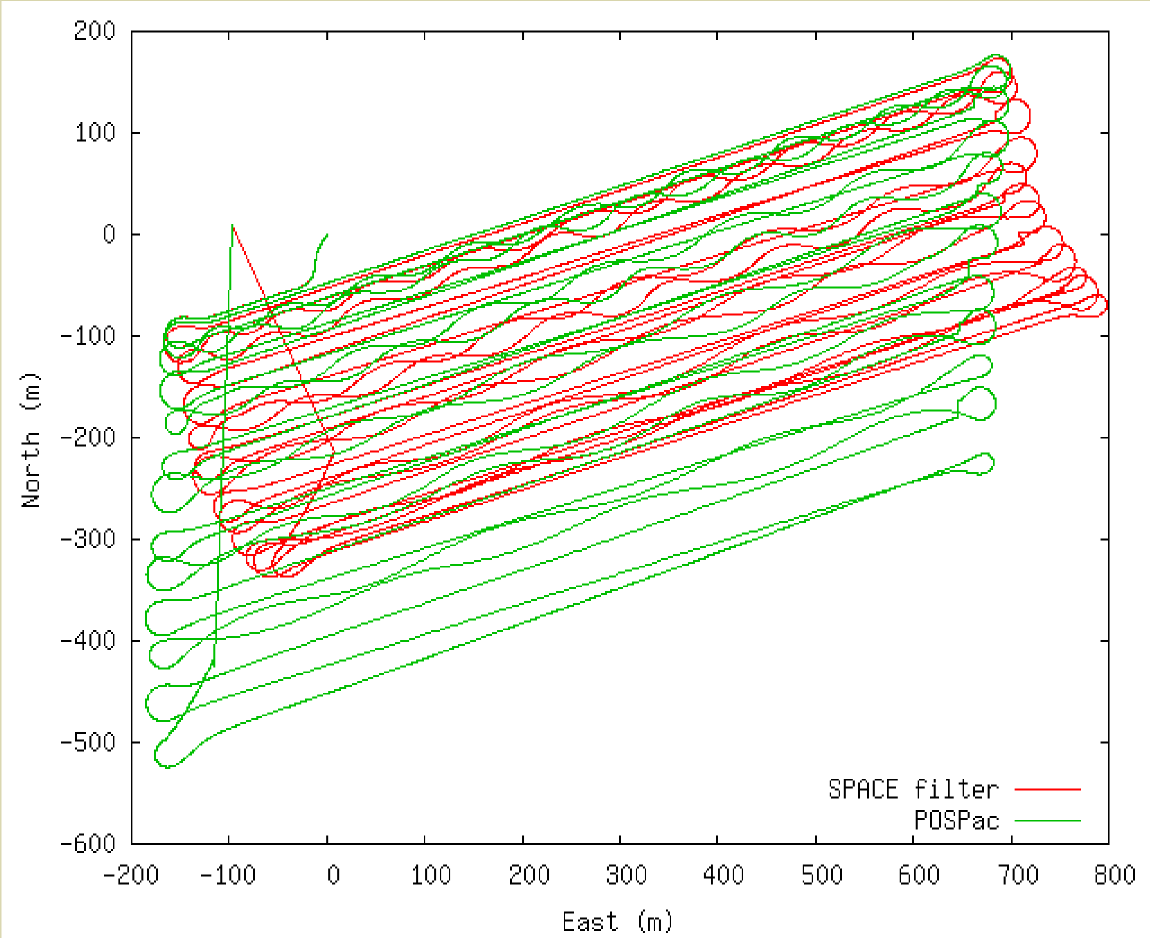


INS Alignment

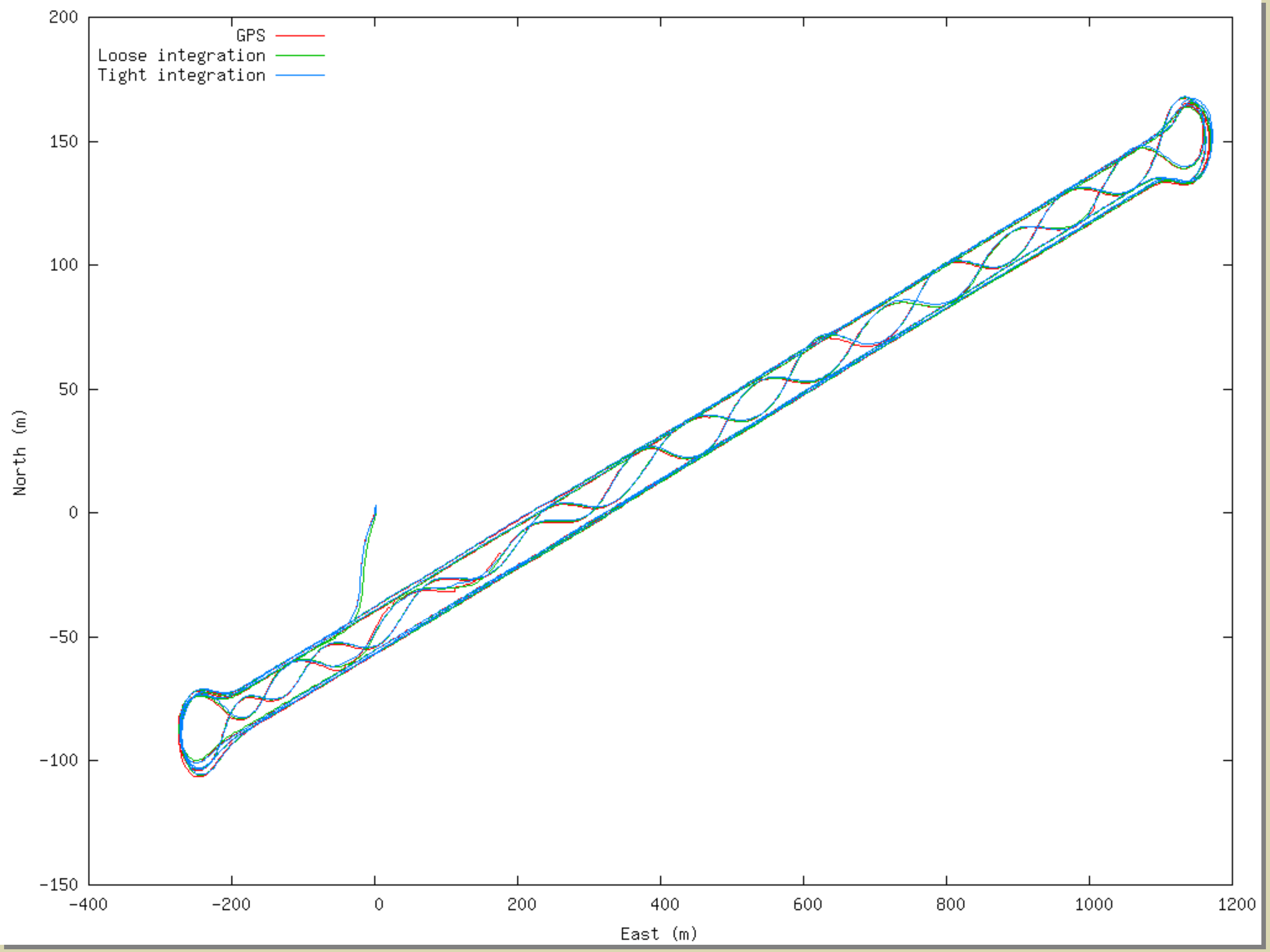
- 2 step approach
  - Coarse alignment using direct equations on averaged data
  - Fine alignment using Kalman filter (ZUPT)
  - Fine alignment required principally for heading initialisation
- ZUPT can be used with IMU of sufficient accuracy to initialise attitude
- Test alignment against Applanix POSPac solution
  - Control over types of measurement update
  - Uses modified state vector heading alignment approach
- Accuracy of ZUPT greatly affects standalone INS performance (for validation)
- Initial attitude uncertainty 5°

Standalone performance

- Position and zero velocity updates at beginning and end of dataset
- SPACE filter drift ~300m
- POSPac drift ~450m
- Performance highly dependent on alignment



GPS and INS integration



SPACE Prototype Test Bed

- A legacy for this phase of the project
- Testing Users' technology, algorithms and data in combination with other Test Bed technology, algorithms and data
- Testing Users' technology on its own
  - Test Bed is a mobile truth
- Demonstration of state-of-the-art and near-future positioning performance
- Physical embodiment of the SPACE research

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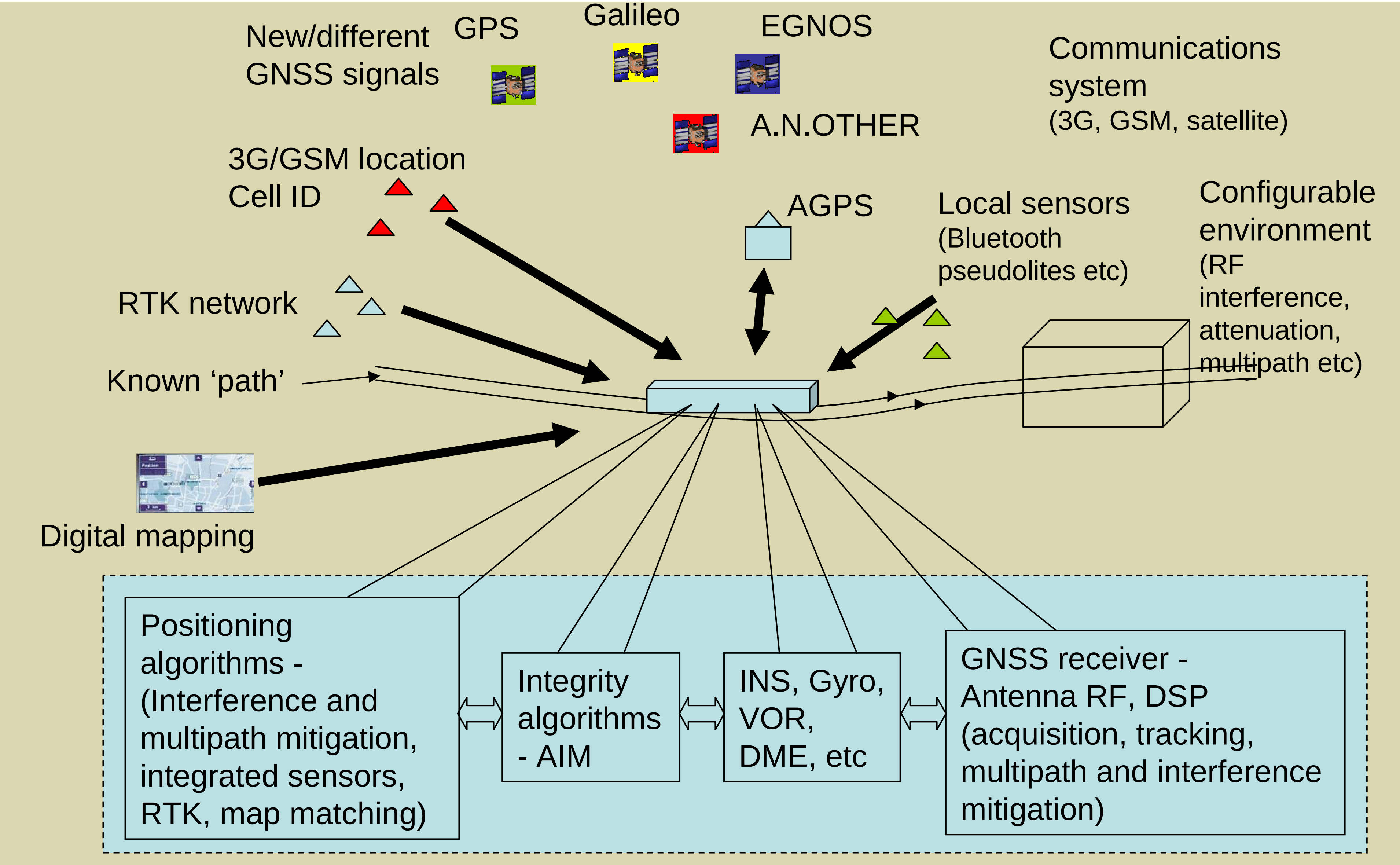

SPACE “1st Generation” Test Bed

Conclusions

- Plug & Play Filter being developed
- Initial trials to establish reference environments
- Kinematic Reference Environment
  - Navigation grade INS
  - Potential for centimetre level reference positioning
- Prototype test-bed to be developed within SPACE

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